Mars Reconnaissance Orbiter

Landing Site Reconnaissance Capability

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Abstract— The Mars Reconnaissance Orbiter (MRO) entered into orbit about Mars on March 10, 2006. After a series of aerobraking and propulsive maneuvers, the spacecraft has been in its sun-synchronous primary science orbit since September 2006 performing both scientific and Mars programmatic support roles. In addition to MRO's scientific investigations of Mars, NASA has tasked MRO to provide reconnaissance of potential landing sites for ongoing and future Mars missions. This paper covers the mission design and analysis process to characterize MRO's landing site coverage capability for all global locations, with special focus on potential sites for future missions: Gale Crater, Mawrth Vallis, and Noachis Human Exploration Zone.

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1. INTRODUCTION

NASA has tasked MRO to provide essential programmatic support to a designated set of ongoing and future missions. One major role of that support activity is the reconnoitering of potential landing sites for various surface craft. The MRO Project and its Science Teams carry out this programmatic function through a Landing Site Reconnaissance (LSR) process that takes advantage of the high-resolution capabilities of the MRO science instruments and the precision surface targeting capabilities of the MRO spacecraft. Quantifying and analyzing the MRO LSR capability is addressed in this paper.

Characterizing the LSR capability can be divided into five components: MRO spacecraft capabilities, primary science orbit, groundtrack characteristics, site revisit frequency, and landing site dispersion ellipse coverage. A critical element underlying the LSR process is the MRO orbit design and the characteristics of its repeating groundtrack. Although greatly aided by the cross-track pointing capabilities of the MRO spacecraft, it is still the fundamental repeat characteristics of the MRO orbit that drive the frequency at which a particular landing area can be fully reconnoitered.

2. MRO SPACECRAFT CAPABILITIES

The MRO spacecraft is 3-axis stabilized with large reaction wheels providing stability and control. In order to reduce pointing errors resulting from navigation uncertainties, the orbiter uses an on-board ephemeris driven pointing algorithm that allows for precise surface targeting. The MRO spacecraft is normally oriented such that its payload elements remain nadir pointed to Mars. Owing to its gimbaled high gain antenna (HGA), the spacecraft can simultaneously acquire science and relay data and return that data to Earth nearly continuously over an orbit (except for periods of Mars occultation or for gaps in DSN coverage). Additionally, the MRO spacecraft can cross-track roll up to ±30° from nadir to enhance its targeting field-of-view (FOV). Gimbaled solar arrays allow the spacecraft to maintain power by sun tracking even while rolling. Science surface targets and relay support passes are scheduled and acquired using an on-board flight software targeting module. The targeting module provides a conflict-free list of observations and relay overflights produced by ground planning software. This list [called the Integrated Target List (ITL)] covers an MRO planning cycle -- two weeks of observations. This ITL contains both rolled (off-nadir, planned for a 2-week period) and nadir (planned weekly) observations. Surface target accuracy is maintained by performing navigation ephemeris updates to the spacecraft twice a week [1].

The primary instrument used for imaging Mars surface targets is the High Resolution Imaging Science Experiment (HiRISE). The 1.15° FOV angle provides HiRISE with a 6 km image swath width and >12 km length (assuming an altitude of 300 km) [1]. The HiRISE image size varies with altitude from a minimum swath width of 5.1 km at 255 km altitude (periapse) to 6.4 km at 320 km (apoapse) [2]. The HiRISE instrument visibility is limited if MRO is restricted to only nadir pointing. By allowing MRO to roll, the HiRISE instrument greatly increases its visibility to potential observations of targets far off the nadir orbital
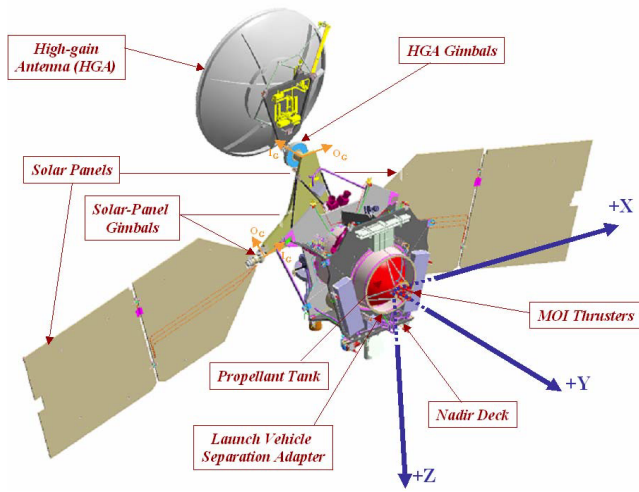
path. Details of the extended HiRISE visibility due to rolling are discussed later in the section.


Figure 1. MRO spacecraft in its typical science orbit configuration [1].

The MRO spacecraft body reference frame is shown in Figure 1, where the +Z axis is along the Nadir Deck direction, and the +Y axis is parallel to the MOI thrusters. The nominal MRO attitude configuration is with the +Z axis pointed nadir to Mars, the +Y axis pointed along the MRO orbit normal direction, and the +X axis approximately along the velocity vector, Figure 2.
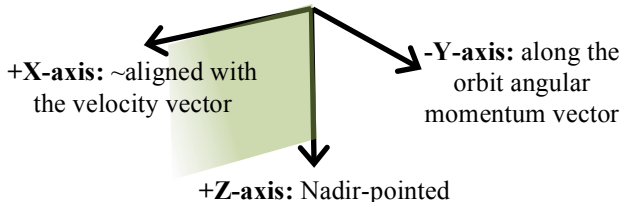

**Figure 2. MRO spacecraft coordinate**

The cross-track roll capability is a rotation about the +X axis, which rotates the Nadir Deck instruments' (including HiRISE) boresite an angle up to ±30° from nadir (in the Z-Y plane), as displayed in Figure 3. Increasing roll angles allow the instruments' potential coverage to be extended farther out (cross-track) for targeted observations. The cross-track reach of the varying roll angles for HiRISE observations is shown in Figure 4. The extent of each roll angle's visibility is defined by the outermost edge of the HiRISE image FOV, as depicted on the right end of the 30° swath [1]. Further examples of the MRO roll capability from an STK simulation are provided in Figures 5a and 5b.
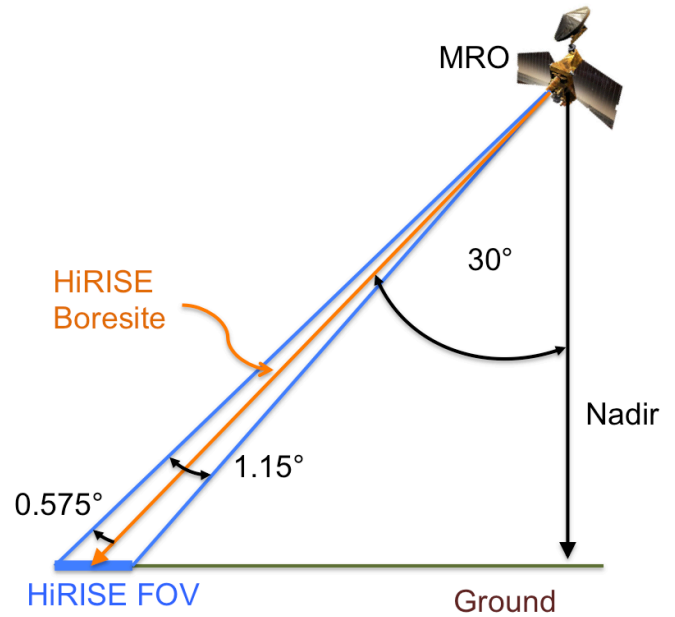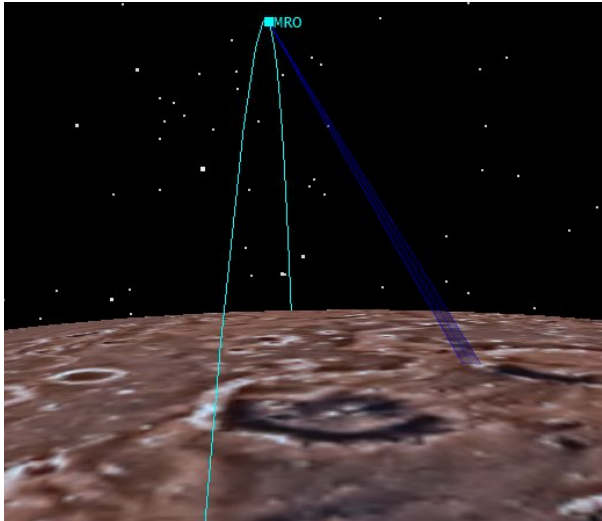

Figure 3. Cross-track roll illustration with HiRISE FOV for 30° roll angle (geometry not to scale).
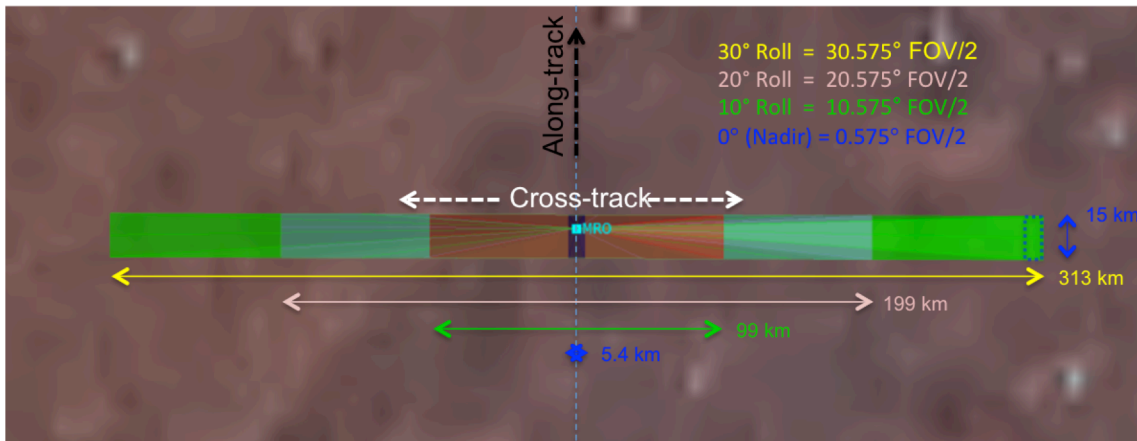
Figure 4. MRO HiRISE cross-track roll visibility for nadir, 10°, 20°, and 30° roll angles (overhead perspective along nadir-direction). HiRISE image FOV is shown at edge of 30° roll visibility swath for reference.
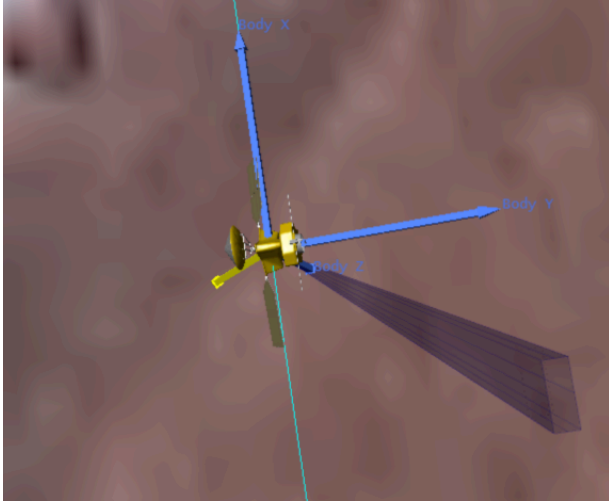
Figure 5b. Illustration of MRO 30° cross-track roll capability with a close-up perspective, showing blue body axes with respect to yellow nadir direction.


Figure 5a. Illustration of MRO 30° cross-track roll capability with an orbital path perspective.
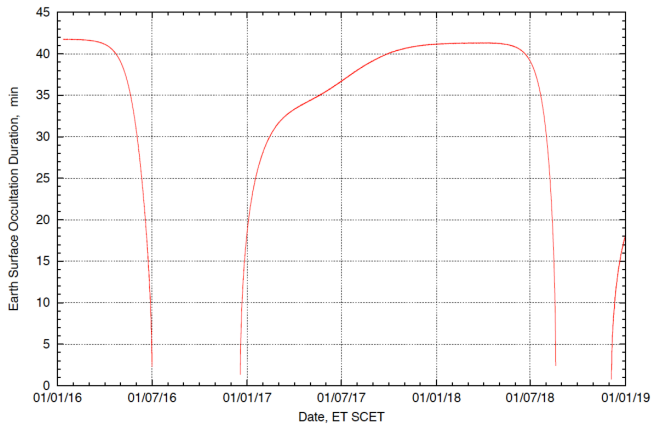
3. PRIMARY SCIENCE ORBIT

The primary science orbit (PSO) was designed to satisfy both science and mission requirements. The orbit has the following characteristics: a sun-synchronous ascending node at 3 pm local mean solar time (daylight equatorial crossing); a periapsis altitude near 255 km; an apoapsis altitude near 320 km; a near-polar inclination of 92.6°; and an eccentricity and argument of periapsis that results in a frozen orbit. The semi-major axis of the orbit was chosen to provide an approximate groundtrack repeat cycle of 17 days [1].

Views of the PSO (in red) from equatorial and polar perspectives are shown in Figure 6. The sun terminator is shown as a yellow line. Some consequences of a 3:00 p.m. LMST orbit are that there are always Sun eclipses and nearly always Earth occultations. Earth occultations cause the orbiter to lose contact with the DSN. This strongly affects the downlink (return) data volume capability of the mission. Earth occultation durations are shown in Figure 7. Note that there is a period when the orbiter is in full view of the Earth continuously for several months at the end of 2016 and 2018. The eclipse durations challenge the orbiter thermal and power designs and are shown in Figure 8. Eclipses and occultations are related to the orientation of the orbit with respect to the Sun and the Earth respectively. The Beta Angle is defined as the angle between the orbit plane and the body in question (Earth or Sun). Beta angles for Earth and Sun are shown in Figure 9 [3].
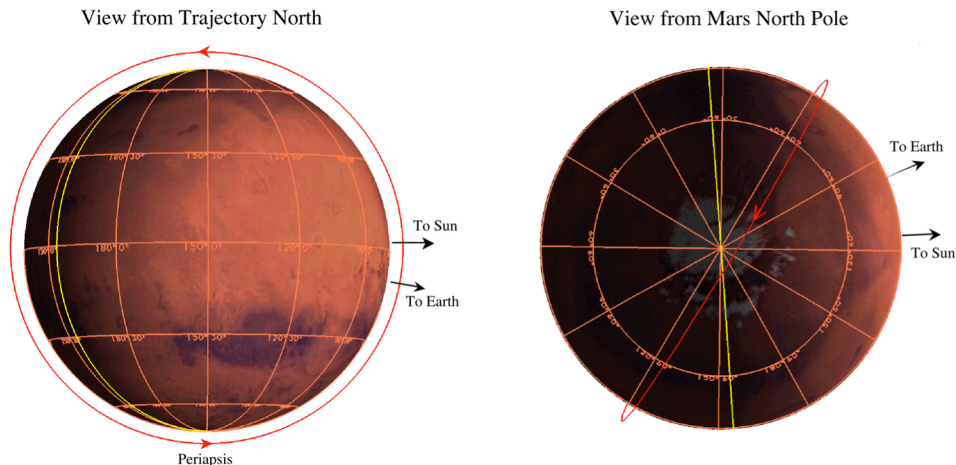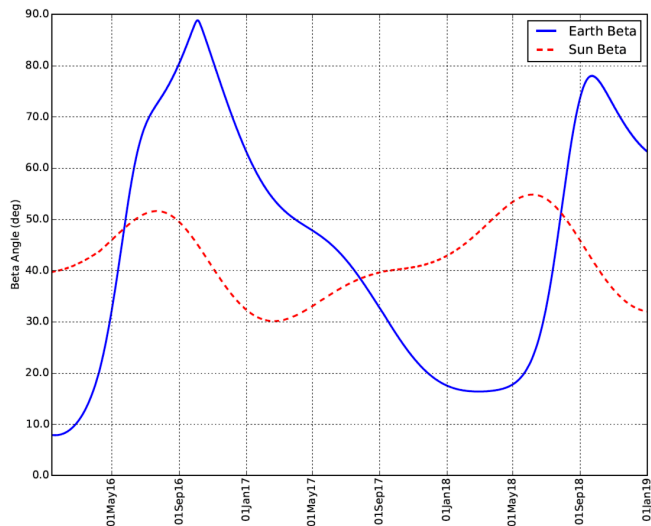

Figure 6. Views of MRO's Primary Science Orbit [1].

**Figure 7. Primary Science Earth Occultation Durations [3].**
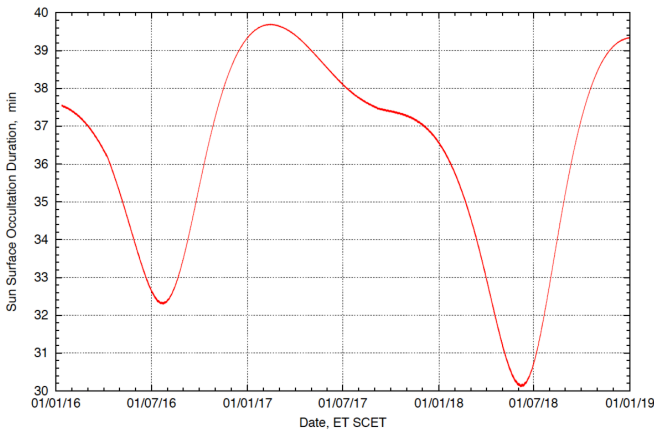
Figure 8. Primary Science Solar Eclipse Durations [3].

Figure 9. Primary Science Earth & Sun Beta Angles [3].

The frozen orbit condition of the PSO causes the periapsis location to remain nearly stationary over the South Pole of Mars. With the periapsis location fixed, a 65-70 km range between the periapsis and apoapsis altitudes results naturally due to the specific shape of the Martian gravity field. Variations in the spacecraft altitude above the surface at specific latitudes are limited to a few kilometers [1]. A plot of altitude vs. latitude is shown in Figure 10. The plot shows 208 days of orbits illustrating the expected variation of altitude due to the gravity field. The ascending portion of the orbit is on the sun-lit side of Mars.
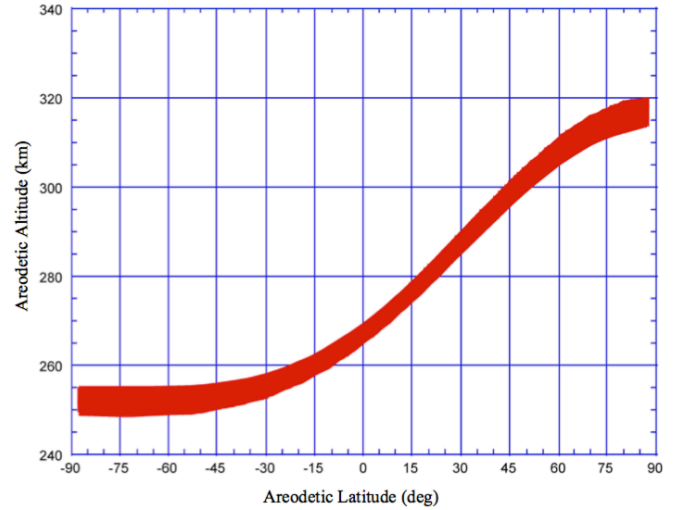
Figure 10 . Primary Science Orbit Altitude vs. Latitude [1].

4. GROUNDTRACK CHARACTERISTICS

Because the science objectives revolve around daily global mapping and profiling, regional survey, and globally distributed targeted observations, the PSO groundtrack is designed to repeat on a short-term basis to provide global access and repeated targeting opportunities as well as to provide long-term global coverage of Mars (over the primary science phase, or PSP) with spacing of less than 5 km.

Figure 11 shows the MRO groundtrack over a 1-sol period. This figure illustrates both ascending (daytime) and descending (nighttime) passes. The progression of MRO's path along the groundtrack is shown by the orbit labels, where 1a and 1d identify the ascending then descending segments of the first orbit, followed by 2a and 2d, etc. Successive groundtracks are separated by 27.3° longitude at the equator. This is illustrated in Figure 12 along with the cross-track visibility for various roll angles of the MRO spacecraft. The PSO groundtrack short-term repeat cycle, or targeting cycle, is 17 days, or every 211 revs. Figure 13 illustrates the build-up of the repeat pattern over this 17 day frequency [3].

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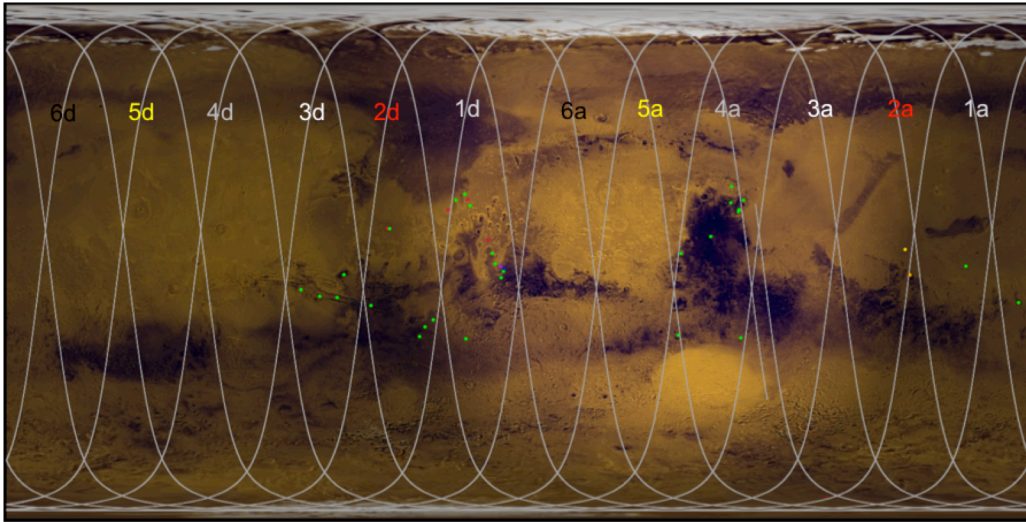
Figure 11. Groundtrack of the MRO spacecraft over a 1 sol period. Colored dots indicate some proposed future landing site locations. The numbered vertical segments represent the ascending and descending passes of the groundtrack from an arbitrary starting point, label 1a.

Figure 12. Successive groundtracks of the MRO spacecraft are separated by 27.3° longitude at the equator.

Figure 13. MRO 17 day groundtrack repeat cycle, showing westward walk of groundtrack [1].

The orbit is designed such that the targeting cycle provides access opportunities to every point on Mars every 17 days within 20° of nadir. The PSO groundtrack builds up fine groundtrack spacing by taking advantage of the westward walk of the target cycle. For example, orbit rev number 212 falls 30.6 km west of rev num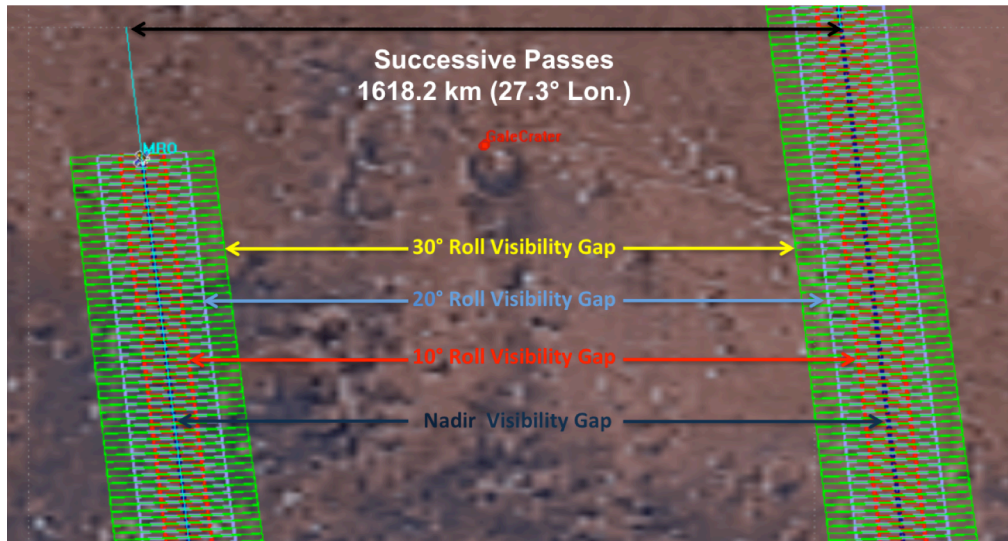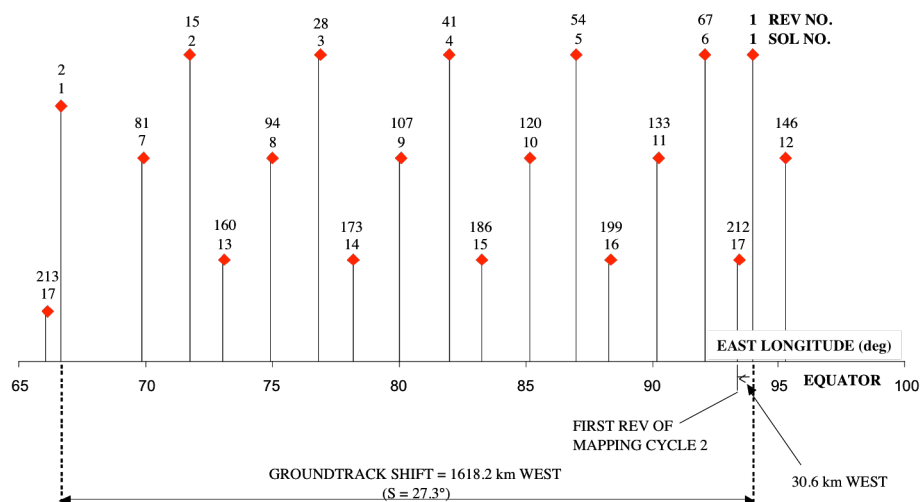ber 1. This westward walk every 17 days provides an overlapping buildup of coverage, provides uniform coverage of Mars within 5 km, and repeats after 4602 revs (359 days). A groundtrack repeat cycle every 5 to 6 days within the 17 day targeting cycle allows the observing opportunities to fall both to the left and to the right of the nadir groundtrack (to enable stereo opportunities). The finest interval at the equator between adjacent groundtracks after 359 days would be 4.64 km, if the orbit could be perfectly maintained. Due to gravity field perturbations, atmospheric drag, and orbit control uncertainties, however, the very fine orbit groundtrack spacing will not be exact. The orbit control strategy uses orbit trim maneuvers (OTM) with very small propulsive burns (approximately 0.2 m/s) to correct the drag induced reduction in the semi-major axis. The remaining variations in the fine orbit spacing due to the uncertainties mentioned above are a few kilometers (i.e. fine spacing could be less than 10 km). The OTMs are planned every 8 weeks unless the estimated ΔV falls below a threshold value of 0.05 to 0.10 m/s.

The PSO groundtrack pattern provides repeated opportunities to observe particular Martian surface sites. The spacecraft is capable of rolling ±30° cross-track of nadir, which is equivalent to a cross-track distance of 145 to 185 km on the surface for the altitude range of the PSO, periapse (255 km) to apoapse (320 km) respectively. The number of opportunities to observe a particular site when the Sun is above the horizon is dependent on the latitude of the site and the roll angle needed to view it. For instance, a given location on Mars will be viewable in daylight 30 - 60 times (depending on latitude) during the primary science phase at roll angles of less than 10° off-nadir. At roll angles of up to 30° off-nadir, the number of viewing opportunities increases to 100 - 200. The highest latitudes have many more opportunities in summer, far fewer (or none) in winter [1].

5. SITE REVISIT FREQUENCY

The MRO spacecraft revisits sites on the surface of Mars with different frequency for various surface locations and site geometry. Revisit frequency is driven primarily by the size and latitude of a given site. Equatorial locations have fewer revisits than higher latitude locations, which is coupled with smaller site areas having fewer revisits than larger sites. Owing to the sun-synchronous orbit design, ascending (South to North) passes are in daylight; descending (North to South) passes are in darkness. The site revisit analysis was performed for the MRO spacecraft with a variety of landing sites. The sites spanned from equatorial to polar latitudes, various longitudes, and with different site area geometries. A focus was placed on potential landing sites for future Mars missions: Gale Crater, Mawrth Vallis, and Noachis Human Exploration Zone (HEZ). Figure 14 shows the landing sites discussed in the revisit analysis.

The analysis assumed the sites had a typical landing dispersion ellipse area of 25 x 20 km. Each landing site
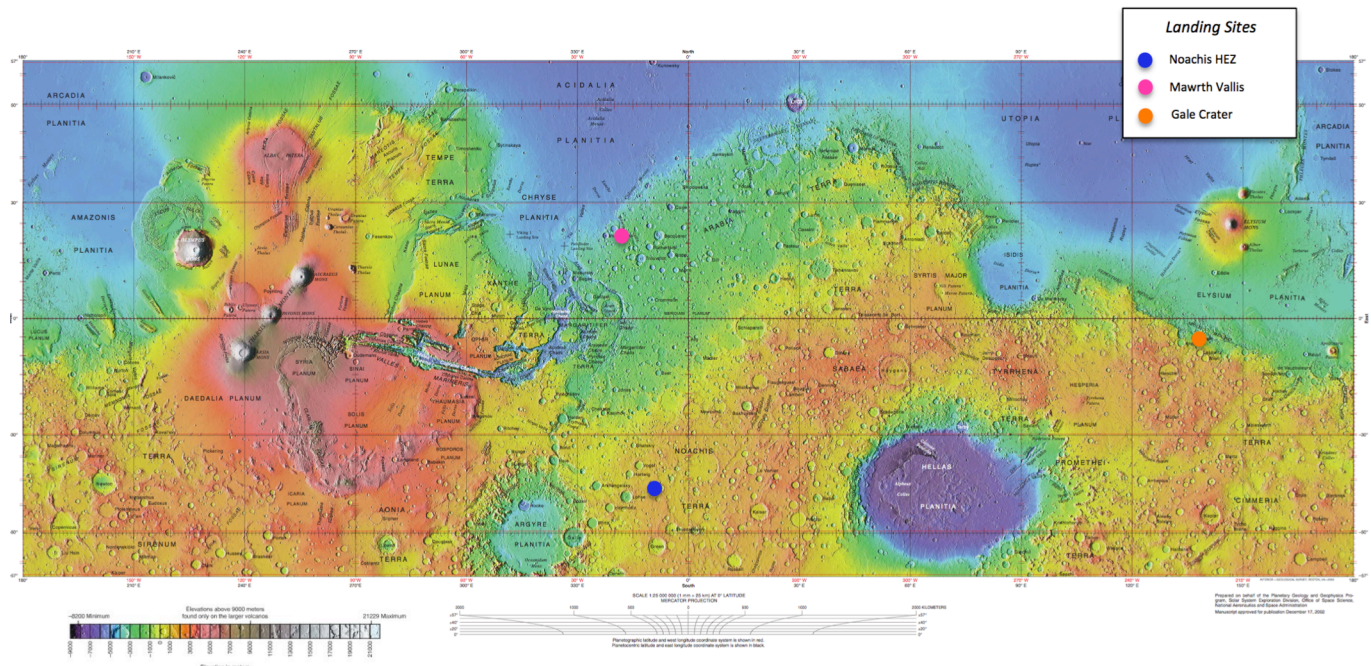
Figure 14. Locations of sites inspected in the MRO revisit analysis. The Noachis HEZ is located at 37.2°S, 350.5°E, Mawrth Vallis is located at 24.9°N, 339.4°E, and Gale is located at 4.5°S, 137.4°E.

ellipse was oriented with its semi-major axis at a 45° angle to the pole as a conservative estimate with respect to MRO's polar orbit and spacecraft configuration. An example of this site area orientation with respect to MRO's HiRISE instrument FOV is in Figure 15.
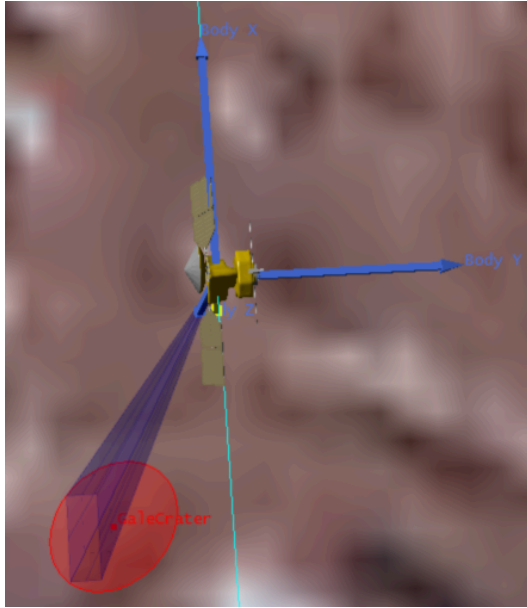
Figure 15. Example MRO observation of landing site dispersion ellipse, displaying MRO's roll visibility coverage and a single HiRISE image FOV.

The analysis was done using the System Tool Kit (STK) software [4]. An accurate MRO orbit reconstruction for March 1, 2014 was used as the initial state for a two-year propagation. The MRO orbit trajectory was propagated using a Mars gravity field of Deg:4 Ord:4 from Feb 13, 2012 – 2014 (730 days). The propagation avoids the need for incorporating atmospheric drag and periodic orbit correction maneuvers because they offset each other's affects on the intended reference trajectory. The two-year time range was chosen because it overlaps previous studies for comparison and verification. The time span also encompasses two complete repeat cycles of MRO's groundtrack (717.2 days) and a full Mars orbit (687 days), capturing a complete range of daylight revisit dynamics. The MRO roll angles incorporated in the analysis were nadir, 5, 10, 20, and 30°. The roll capability was implemented using an adjusted visibility FOV for each: 0.575, 4.425, 9.425, 19.425, and 29.425° respectively. These adjusted visibility FOV angles for off-nadir rolls assume a revisit is counted when the entire HiRISE image swath is within the site ellipse area. The HiRISE FOV angle (0.575°) is simply subtracted from the original roll angle to achieve the more conservative revisit measurement. The time between each revisit (in days) is recorded and averaged over the two-year range and displayed in Table 1. The time between each revisit may vary greatly, especially for small roll angles (< 5°), where the revisit is highly sensitive to orbital dynamics. For example the Gale nadir revisit time of 44.4 days has a standard deviation (1-σ) of 27.8 days, while the Gale 30° roll revisit time of 5.1 days has a 1-σ of only 1.3 days. The larger roll visibility FOVs decrease the revisit sensitivity to orbital dynamics. The variability of the revisit data for each site is represented in Tables 2 - 4. The time between revisits is shown to decrease for higher latitudes of the non-nadir roll angles. The exception for the nadir pointing cases is caused by the increased sensitivity to orbital dynamics disrupting the effects due to latitude [5]. A more detailed sample of the revisit data is shown in the next section as it aids in the site area coverage discussion.

Table 1. MRO revisit time in days for potential landing site dispersion ellipses (25 × 20 km).

Ground Site	Average Revisit Time (days)				
	Nadir	5° Roll	10° Roll	20° Roll	30° Roll
Gale Crater (4.5° S, 137.4° E)	44.4	24.1	14.9	7.7	5.1
Mawrth Vallis (24.9° N, 339.4° E)	51.2	20.8	12.3	6.4	4.1
Noachis HEZ (37.2° S, 350.5° E)	36.8	17.8	10.4	5.5	3.6

Table 2. MRO revisit time statistics for Gale Crater 25 × 20 km landing site dispersion ellipse.

Gale Crater (4.5° S, 137.4° E):	Average Revisit Time (days)				
Revisit (days)	Nadir	5° Roll	10° Roll	20° Roll	30° Roll
Avg	44.4	24.1	14.9	7.7	5.1
Min	16.4	16.4	5.1	5.1	1.0
Max	77.1	60.6	16.4	11.3	6.2

Table 3. MRO revisit time statistics for Mawrth Vallis 25 × 20 km landing site dispersion ellipse.

Mawrth Vallis (24.9° N, 339.4° E):	Average Revisit Time (days)				
Revisit (days)	Nadir	5° Roll	10° Roll	20° Roll	30° Roll
Avg	51.2	20.8	12.3	6.4	4.1
Min	6.7	6.7	1.5	0.5	0.5
Max	93.5	44.2	16.4	11.3	6.2

Table 4. MRO revisit time statistics for Noachis HEZ 25 × 20 km landing site dispersion ellipse.

Noachis HEZ (37.2° S, 350.5° E):	Average Revisit Time (days)				
Revisit (days)	Nadir	5° Roll	10° Roll	20° Roll	30° Roll
Avg	36.8	17.8	10.4	5.5	3.6
Min	3.6	3.6	1.5	1.5	1.0
Max	77.1	44.2	16.4	11.3	6.2

The MRO site revisit problem was further expanded by analyzing similar 25 × 20 km site ellipses, spanning all latitudes and longitudes. The northern and southern hemisphere locations were analyzed separately. Landing site ellipses were placed every 5° in latitude from the equator to each pole and staggered every 60° in longitude around Mars, providing global coverage for the analysis. All of the longitudinal data was averaged by a polynomial trendline fitted for each roll angle data set. These smoothed trendline graphs are found for the northern and southern hemisphere latitudes in Figures 16 and 17 respectively, as well as shown overlaid on the same plot in Figure 18. Each trendline shows a peak and/or plateau in revisit time at sites close to the equator followed by a nearly linear trend of decreasing revisit times with higher latitudes. Southern latitude site revisit curves are consistently shifted/stretched toward higher latitudes (toward the right), where each site's latitude has a longer revisit time compared to the northern sites.
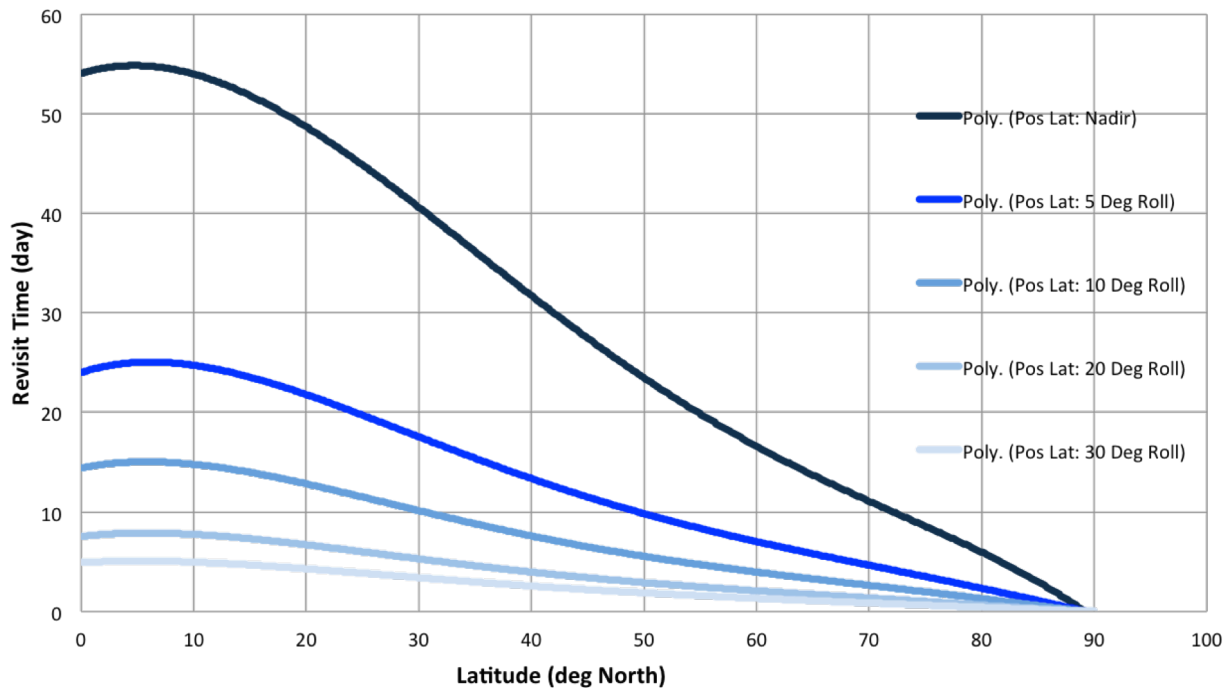
Figure 16. MRO average daylight revisit time for northern site latitudes using a polynomial-smoothed trendline with 25 × 20 km ellipse geometry.
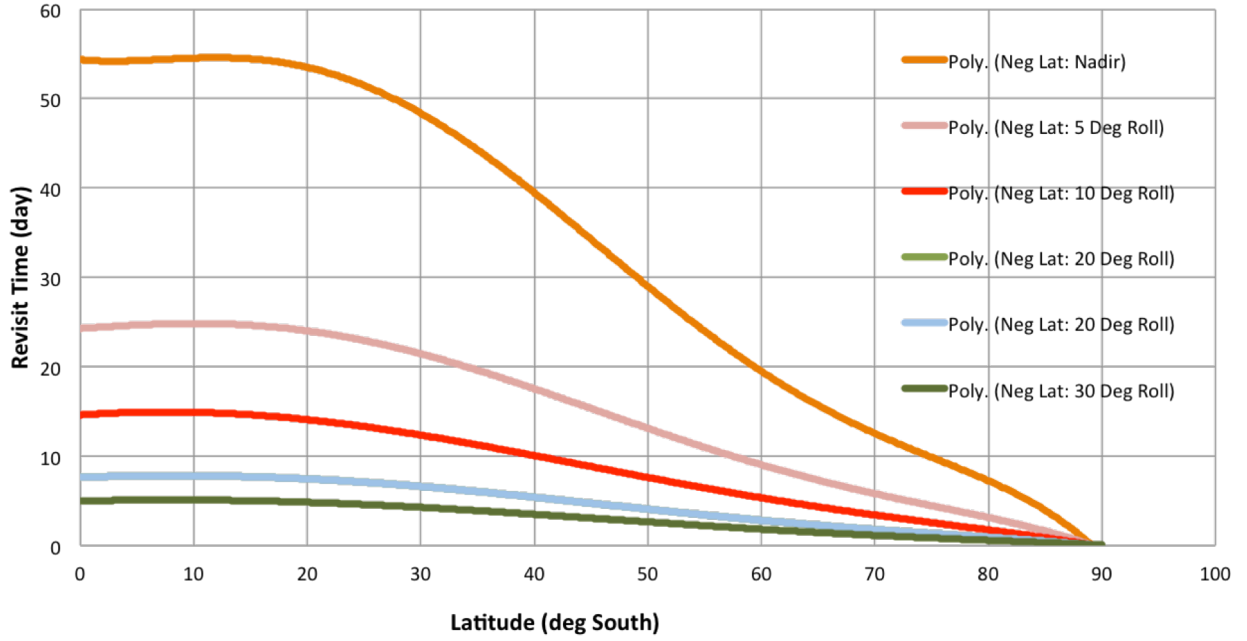
Figure 17. MRO average daylight revisit time for southern site latitudes using a polynomial-smoothed trendline with 25 × 20 km ellipse geometry.
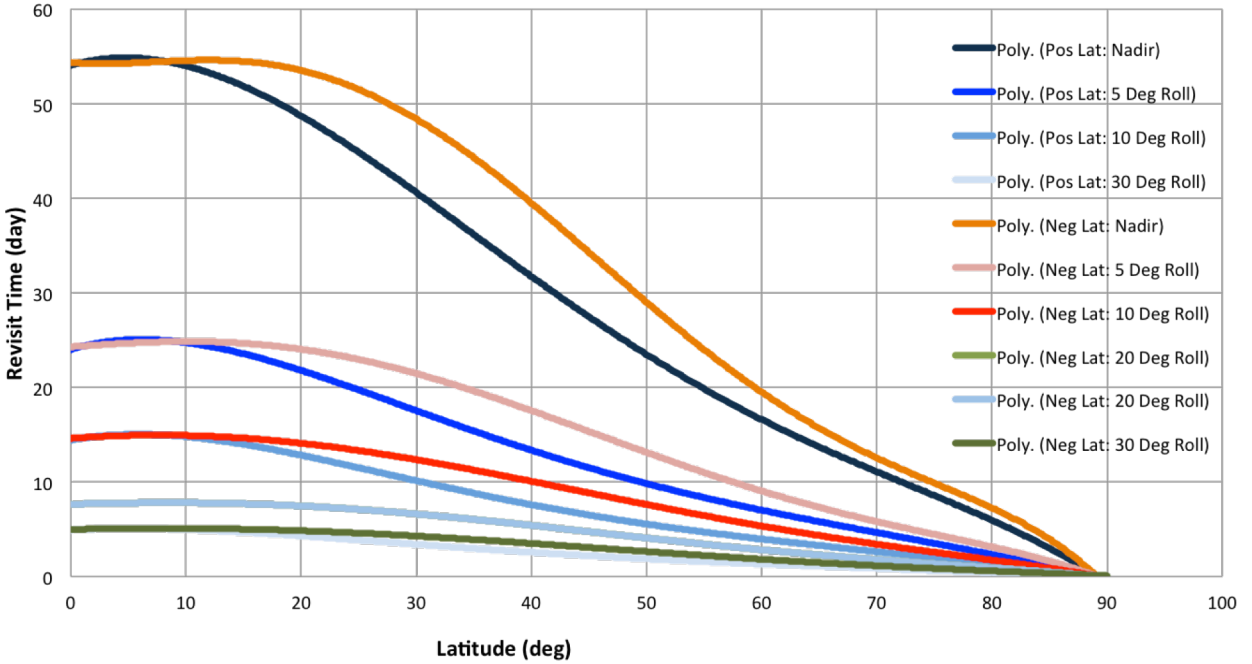

Figure 18. MRO average daylight revisit time for all latitudes using a polynomial-smoothed trendline with 25 × 20 km ellipse geometry.

6. LANDING SITE COVERAGE

An important aspect of the MRO landing site reconnaissance function is the extension of the repeat frequency analysis to a particular site of interest; i.e. the time that it takes to cover a specific area on the surface, such as a landing site dispersion ellipse. The coverage time for a particular site is determined by two factors: how many HiRISE image swaths are required to completely cover a predefined landing dispersion ellipse and the associated time to revisit the site, assuming only one image per pass. The primary parameter used to compare coverage of different sites is the average coverage time. The average coverage time (T_C) is simply the average revisit time (T_R) multiplied by the number of required passes (N_P) [5]:

$$T_C = T_R \cdot N_P \qquad (1)$$

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A more accurate measurement of coverage time requires extensive manual implementation to target each revisit image for a particular site area and time period; therefore it is not suitable for such a broad analysis. It should be noted that using an average coverage time assumes that additional revisit passes and associated time may be required to completely image a site area, especially for cases restricted to small roll angles (< 5°). For general coverage investigations, the average coverage time not only gives a useful estimate, but also provides deeper insight to the global LSR problem.

The coverage analysis is presented for a typical landing dispersion ellipse geometry of 25 × 20 km at various latitude and longitude locations. The HiRISE FOV image dimensions are 5.4 km swath width (cross-track) and 15 km length (along-track), which assumes an altitude of 265 km, illustrated in Figure 19. The chosen altitude and HiRISE image size is an average of the typical observing scenarios.
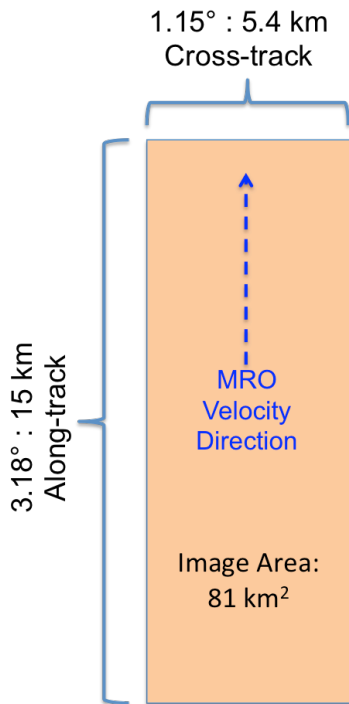

Figure 19. HiRISE FOV image dimensions (cross-track swath width and along-track length) and image area [2]

The many different configurations of the landing dispersion ellipse and HiRISE FOV orientation can be summarized with a conservative number of passes required for complete coverage and a minimum number of passes. The 25 × 20 km landing ellipse requires at least 8 passes, while 10 revisit passes provides extra margin for difficult configurations, demonstrated in Figure 20. As another example, Figure 21 displays a smaller 13 × 7 km landing ellipse, requiring only 2-3 revisit passes for full coverage. All of the following analysis will use a 25 × 20 km landing ellipse.

The larger number of passes for a conservative coverage strategy accounts for more difficult site area geometry and/or HiRISE FOV orientation with respect to the landing ellipse. If necessary, additional passes can be applied on top of the minimum/ and conservative numbers to allow for corrupted image data, spacecraft issues, or any other unforeseen events that result in missed passes.

Conservative 10 Passes
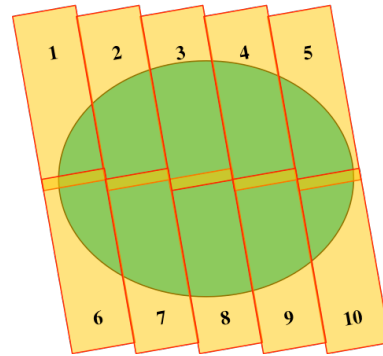
Minimum 8 Passes
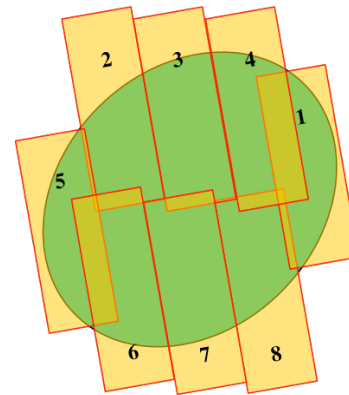
Figure 20. Subdividing 25 × 20 km site with 5.4 x 15 km swaths, showing conservative and minimum number of revisit passes to provide complete HiRISE coverage.

Conservative 3 Passes   Minimum 2 Passes
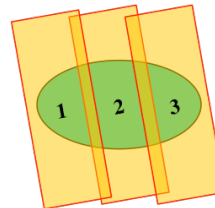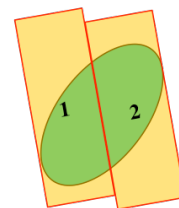
Figure 21. Subdividing 13 × 7 km site with 5.4 x 15 km swaths, showing conservative and minimum number of revisit passes to provide complete HiRISE coverage.

Using the site revisit results for the Gale Crater, Mawrth Vallis, and Noachis HEZ locations, the average coverage time is determined with a minimum and conservative number of passes, Table 5. Utilizing the MRO roll capability significantly reduces the average number of days

required for complete site coverage. Allowing just 5° roll cuts the coverage time in half compared to nadir pointing. Using the full 30° roll capability achieves an order of magnitude reduction in coverage time.   The average coverage time for non-nadir roll angles also decreases with higher site latitudes, as defined by the revisit values.

especially for smaller roll angles and nadir pointing. Though the revisit times can have large variation, they also have a relatively consistent pattern. The consistent set of revisit times provide a reliable average revisit time to be used in the coverage time analysis.

Table 5. Minimum and conservative coverage time (days) for potential landing site locations, various MRO roll angles, and 25 × 20 km ellipse geometry.

Ground Site	# Passes	Average Coverage Time (days)				
		Nadir	5° Roll	10° Roll	20° Roll	30° Roll
Gale Crater	Min: 8	355.1	192.7	119.2	61.8	40.6
(4.5° S, 137.4° E)	Con: 10	443.9	240.9	149.0	77.3	50.8
Mawrth Vallis	Min: 8	409.7	166.0	98.5	51.0	32.7
(24.9° N, 339.4° E)	Con: 10	512.2	207.6	123.1	63.7	40.8
Noachis HEZ	Min: 8	294.4	142.0	83.5	44.0	29.0
(37.2° S, 350.5° E)	Con: 10	368.0	177.5	104.4	55.0	36.3

Within the two-year propagation range of the analysis, there are many different windows of consecutive revisits to complete the required number of passes for full 25 × 20 km site coverage. For example, the conservative set of 10 consecutive revisit passes can be placed as a sliding window anywhere along the numerous site revisits within the two-year propagation time. A group of consecutive revisit passes are selected for the Gale Crater site and of each roll angle, as shown in Table 6. The revisit time (days) is shown for each pass and roll angle, then summed for the required coverage time. As described in the revisit analysis section, the revisit time between each pass can vary greatly,

All of the potential coverage windows and associated coverage times of the 10-pass scenario were compiled for each landing site. The resulting coverage statistics are provided in Tables 7 - 9 for Gale Crater, Mawrth Vallis, and Noachis HEZ respectively. The coverage time is shown to have quite low variability (1-σ typically <10% of the average coverage time), which reinforces the reliability of the revisit times as previously concluded. The variation of coverage time also displays a relationship with site latitude, where higher latitudes increase the variability and extremums. The higher latitude landing site Noachis HEZ has a 1-σ coverage time up to 26% from its average.

Table 6. Example set of 10 consecutive MRO site revisits (days) for 25 × 20 km Gale Crater landing ellipse full coverage at various roll angles.

Gale Crater (4.5° S, 137.4° E):	Site Revisit Time (days)				
Revisit #	Nadir	5° Roll	10° Roll	20° Roll	30° Roll
1	16.4	16.4	5.1	6.2	6.2
2	60.6	16.4	11.3	5.1	5.1
3	16.4	27.7	16.4	11.3	5.1
4	77.1	16.4	16.4	5.1	6.2
5	77.1	16.4	16.4	11.3	5.1
6	16.4	44.2	11.3	5.1	5.1
7	77.1	16.4	16.4	11.3	6.2
8	16.4	16.4	16.4	5.1	5.1
9	77.1	60.6	16.4	11.3	5.1
10	16.4	16.4	16.4	5.1	1.0
Coverage Time:	451.1	247.6	142.8	77.1	50.3

Table 7. MRO site coverage statistics for 25 × 20 km Gale Crater site coverage at various roll angles.

Gale Crater (4.5° S, 137.4° E):	Site Coverage Time (days)				
Coverage	Nadir	5° Roll	10° Roll	20° Roll	30° Roll
Average	456.7	250.9	147.3	77.4	50.5
Minimum	418.2	219.9	137.7	77.1	44.2
Maximum	495.3	291.8	159.3	82.2	55.5
1-σ	28.3	19.8	8.5	1.3	3.4

Table 8. MRO site coverage statistics for 25 × 20 km Mawrth Vallis site coverage at various roll angles.

Mawrth Vallis (24.9° N, 339.4° E):	Site Coverage Time (days)				
Coverage	Nadir	5° Roll	10° Roll	20° Roll	30° Roll
Average	525.2	212.6	126.5	64.6	41.3
Minimum	478.8	154.1	77.1	32.9	18.0
Maximum	582.1	247.6	142.8	71.9	49.3
1-σ	43.1	24.9	14.3	8.1	6.5

**Table 9. MRO site coverage statistics for 25 × 20 km Noachis HEZ site coverage at various roll angles.**

Noachis HEZ (37.2° S, 350.5° E):	Site Coverage Time (days)				
Coverage	Nadir	5° Roll	10° Roll	20° Roll	30° Roll
Average	337.0	166.3	104.6	54.4	35.9
Minimum	308.3	93.5	60.6	26.7	19.0
Maximum	361.2	231.2	142.8	66.8	44.2
1-σ	19.0	40.7	25.2	13.9	9.1

Similar to the revisit analysis, the site coverage investigation is expanded to include all latitude and longitude site locations. The average site coverage time is determined utilizing the average revisit time data available from the previous section and multiplying by 10 revisit passes. The resulting conservative coverage time for each latitude is shown for northern and southern hemisphere landing sites in Figure 22 as a polynomial trendline average of all corresponding longitude data, similar to the revisit analysis. As expected, all of the same trends found in the revisit analysis is also reflected here, such as the shift in southern hemisphere site coverage time toward higher latitudes compared to the northern hemisphere curves.

7. SUMMARY

MRO's highly refined repeating groundtrack orbit coupled with its cross-track roll capability enables rapid site revisit and complete area coverage. Assuming a 25 × 20 km ellipse site area representative of a typical landing dispersion footprint, an equatorial site can potentially have full MRO HiRISE image coverage in less than 50 days using 30° roll. For comparison, the same equatorial site can require more
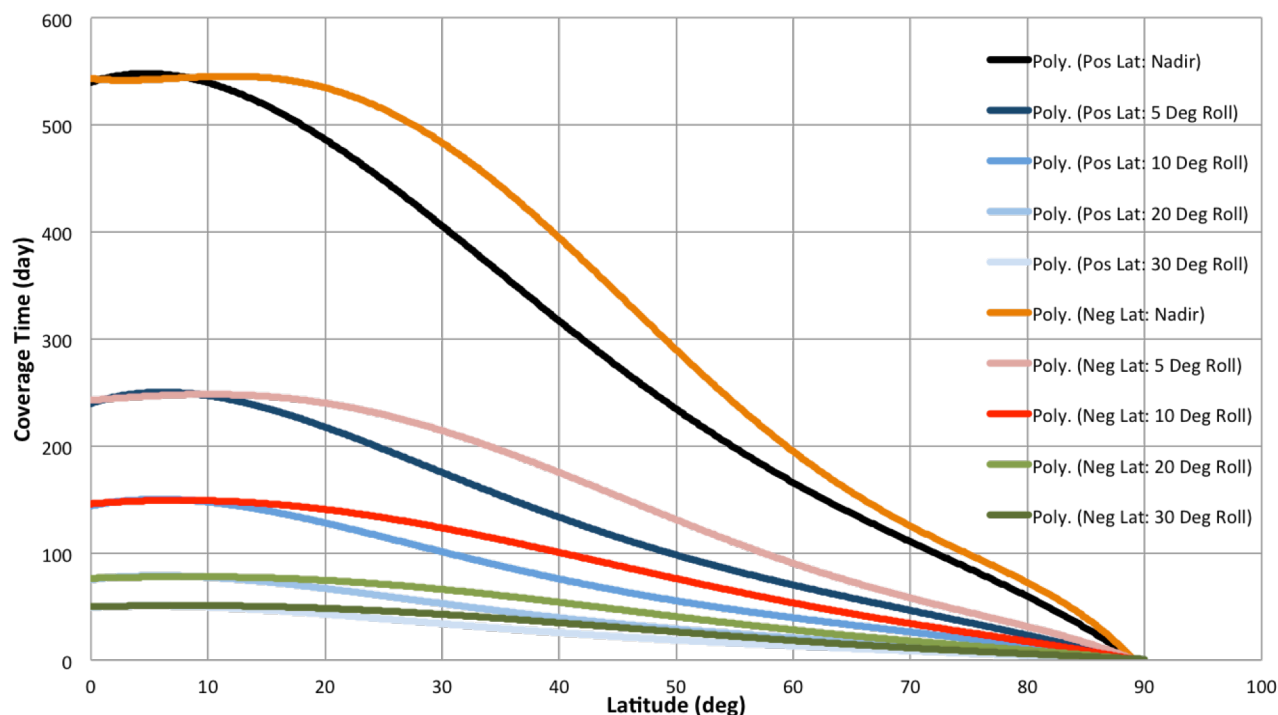
Figure 22. MRO average daylight site coverage time for all latitudes using a polynomial-smoothed trendline average of all corresponding longitudes with 25 × 20 km ellipse geometry.

than 550 days when restricted to only nadir pointing, an order of magnitude difference. Even a small cross-track roll angle of 5°, reduces the site coverage time in half. Allowing MRO off-nadir rolling also enables targeted imaging within a site area to ensure that each pass captures an optimally placed HiRISE image. Implementing an MRO roll angle of at least 10° delivers a significant reduction in revisit time (more than 70% reduction compared to nadir pointing) and gives each pass the freedom to target a site image anywhere within a 50 km cross-track range (assuming an altitude of 265 km), therefore providing efficient site coverage.

ACKNOWLEDGEMENTS

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BIOGRAPHY

Marty Brennan graduated from Mississippi State University with a B.S. in Aerospace Engineering in 2008 and received his Ph.D. focused in Orbital Mechanics from the University of Texas at Austin in 2015. He immediately transitioned into JPL and was able to get on board a variety of missions and tasks. He is currently a Science Planning Engineer on the Cassini Mission and a Mission Planner for the Juno Mission. In addition to performing orbital analysis for MRO, he had an active role as a Mission Formulation Systems Engineer in the Ice Giants Mission decadal study.
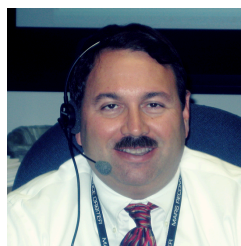
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